PHOSPHORUS REMOVAL IN SEASONAL RETENTION LAGOONS BY BATCH CHEMICAL PRECIPITATION

RESEARCH REPORT NO. 13

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CANADA-ONTARIO AGREEMENT

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PHOSPHORUS REMOVAL IN SEASONAL RETENTION LAGOONS BY BATCH CHEMICAL PRECIPITATION

by

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RESEARCH PROGRAM FOR THE ABATEMENT OF MUNICIPAL POLLUTION WITHIN THE PROVISIONS OF THE CANADA-ONTARIO AGREEMENT ON GREAT LAKES WATER QUALITY

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ABSTRACT

As a result of a Province of Ontario policy requiring phosphorus removal at municipal and institutional wastewater treatment facilities in certain areas of the province, it became necessary to develop a method of reducing the total phosphorus content in waste stabilization pond effluents to below 1.0 mg/l. One possible method of achieving this in seasonal retention lagoons is through batch chemical treatment of the pond contents prior to discharge.

Three prime coagulants have been field tested; eleven treatments have been carried out using alum, four with ferric chloride and two using lime. The required chemical dosage was determined by jar tests using lagoon contents. Using alum and ferric chloride, it was found that these jar tests were highly reliable in predicting the required chemcial dosage and resulting lagoon quality.

The chemicals were dispersed and mixed with outboard motorboats; labour requirements ranged from 1.5 - 2.0 man-hours per acre (3.75 - 5 man-hours per ha) to treat a lagoon with a liquid chemical, and from 1.4 - 25 man-hours per acre (3.5 - 62 man-hours per ha) to treat with a dry chemical. Lagoon discharge was usually begun the day after treatment and was completed, on average, 8 days later.

Both the alum and ferric chloride coagulants produced a high quality effluent. The total phosphorus content was normally well below 1.0 mg/l and the BOD was usually below 10 mg/l. The lime applications produced conflicting results with one treatment exhibiting good initial reduction in phosphorus and BOD with rapid deterioration of the achieved water quality after treatment, while the second treatment failed to reach the 1.0 mg/l residual total phosphorus requirement.

Batch chemical treatment of seasonal retention lagoons with alum or ferric chloride is an effective means of

reducing the total phosphorus content in the pond effluent to below 1.0 mg/l. Additional benefits usually obtained are reduced BOD and suspended solids concentrations to produce a high quality effluent.

RÉSUMÉ

En raison de la politique de gouvernement ontarien exigeant l'élimination du phosphore provenant des installations municipales et industrielles de traitement des eaux usées dans certaines parties de la province, il s'est révélé nécessaire d'élaborer une méthode permettant de réduire à moins de 1.0 mg/l la teneur en phosphore total des effluents des étangs de stabilisation. Une des solutions pour y parvenir dans les bassins saisonniers de stabilisation est le recours au traitement chimique en discontinu du contenu des étangs avant leur écoulement.

On a testé sur les lieux trois coagulants efficaces; on a effectué onze traitements à l'alun, quatre au chlorure de fer (III) et deux à la chaux. On a déterminé la quantité de produits chimiques nécessaires à l'aide d'essais en laboratoire effectués sur des échantillons d'eau provenant de bassins. Pour l'alun et le chlorure de fer (III), on a observé que ces essais permettaient de prévoir avec beaucoup de fiabilité les quantités des produits à ajouter et la qualité résultante des eaux du bassin.

On a solubilisé et mélangé les substances à l'aide d'embarcations munies de hors-bords; le travail nécessaire au traitement d'un bassin à l'aide d'un produit chimique liquide a été de 1.5 à 2.0 heures-hommes l'acre (3.75 à 5 heures-hommes l'hectare) et de 1.4 à 25 heures-hommes l'acre (3.5 à 62 heures-hommes l'hectare) pour le traitement à l'aide d'un produit solide. Habituellement, on commençait à vider le bassin la journée suivant le traitement et l'opération de vidage se terminait, en moyenne, 8 jours plus tard.

Les coagulations à l'alun et au chlorure de fer (III) ont donné des effluents de très bonne qualité. La teneur en phosphore total était généralement inférieure à 1.0 mg/l et la DBO, inférieure à 10 mg/l. Les applications de chaux ont

amené des résultats contradictoires: une des applications a donné une bonne élimination initiale du phosphore et de la DBO, qui s'est cependant détériorée rapidement par la suite, tandis que la seconde application n'a pas permis d'atteindre la limite de 1.0 mg/l en phosphore résiduel.

Le traitement chimique par ajouts discrets de chlorure de fer (III) ou d'alun aux bassins saisonniers de rétention est une méthode efficace permettant de réduire la teneur en phosphore total de l'effluent de l'étang à moins de 1.0 mg/l. Les avantages supplémentaires sont la réduction de la DBO et des matières en suspension, ce qui donne un effluent de qualité supérieure.

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1. INTRODUCTION

As a result of the International Joint Commission report of 1969, the Province of Ontario adopted a policy requiring 80 per cent phosphorus removal from wastewater treatment plant influents eventually entering the Lower Great Lakes and inland recreational waters, by the end of 1973 or 1975, depending on the location in the province. This was later modified to an effluent total phosphorus level of 1.0 mg/l or less for specific areas (Canada-U.S. Agreement, 1972). One practical means of effecting this degree of phosphorus reduction in waste stabilization ponds is chemical treatment within the existing facility, either through continuous or batch chemical addition. The latter method will be discussed here.

The areas in which additional information was required regarding the batch chemical treatment of lagoons were:

1. chemicals that can be used effectively for phosphorus removal,
2. most efficient means of chemical dispersion,
3. possible recirculation of precipitated phosphorus after treatment,
4. feasibility of large cell application,
5. cumulative effects in repeated applications,
6. effects of algae on batch treatment and vice versa, and
7. effectiveness of treating a single cell still receiving raw sewage.

In order to obtain this information, various chemicals were used both in laboratory studies and numerous full scale treatments in different lagoons.

2. BACKGROUND

In recent years, eutrophication, or the over-abundance of nutrients, has become a serious problem in the Lower Great Lakes. It is generally accepted that reducing the phosphorus loads coming into these lakes will improve the situation (Sawyer, 1968; Shapiro, 1970; Vallentyne et al., 1970; and Hamilton, 1971). As stated earlier, the International Joint Comission has acted upon this information and put forward guidelines that will limit the amount of phosphorus entering these lakes from sewage effluents.

One means of reducing the phosphorus content in wastewater is by chemical precipitation using one of the common coagulants, such as aluminum sulphate, ferric chloride or calcium hydroxide. This form of treatment is commonly associated with conventional mechanical sewage treatment plants (Lea et al., 1954; Malhotra et al., 1964; Nilsson, 1969; and Vollenweider, 1968). However, emptying into the Lower Great Lakes basin are many waste stabilization ponds, some of which are operated on a seasonal retention (fill and draw) basis. The problem of phosphorus removal in these installations had to be considered.

It was decided to attempt a batch type of chemical application for phosphorus removal in such systems. In order to distribute the chemical in a reasonably uniform manner within the lagoon and achieve sufficient mixing, motorboats were used containing chemical storage tanks which discharged the liquid or slurry into the prop-wash. This concept of batch chemical treatment, to reduce phosphorus levels, has also been used on two lakes (Jernelov, 1970 and Wall et al., 1971).

Certain additional advantages have been reported with batch chemical treatment. Lin et al., 1971, found that chemicals such as alum are useful in reducing algal popu-

lations. Nilsson, 1969, reported that there was a reduction in BOD, suspended solids and coli bacilli when chemical precipitants were added in sewage treatment plants.

3. METHODS

3.1 Site Evaluation

On the primary visit to the lagoon site being considered for treatment, the physical facilities were examined. The access road to the lagoon was visually assessed for 50-ton (45 metric tons) carrying capacity in early spring and late fall. If heavy vehicular delivery did not seem feasible, the possibility of piping the chemical to the edge of the lagoon was examined.

Structural facilities were checked to insure that the diversion of influent was possible during treatment and discharge in multiple cell installations, and also that separate discharge facilities were available.

The mean depth of the lagoon was ascertained by taking numerous random soundings with a graduated weighted line. The lagoon was checked for obstructions that would make power boat operation hazardous.

3.2 Dosage Determination

A 10-gallon (45.5 litre) sample of surface lagoon water was collected from each cell to be treated. Although not probable, it was felt that waste characteristics, modes of operation, age of the lagoon, etc., could effect different dosage requirements in cells of the same system.

The 10 gallon (45.5 litre) samples were returned to the laboratory for jar testing in order to determine the optimum chemical and dosage required to effect the necessary degree of phosphorus removal. On-site testing was not considered to be essential because of the long retention period within the stabilization pond thus making rapid changes in pond characteristics unlikely.

The jar testing consisted of adding a dosage range of the test chemical to 2 litre samples of the lagoon water being mixed with a Phipps and Bird multiple laboratory

stirrer at 200 rpm. Dosage ranges used in the jar testing were: lime 50-350 mg/l, alum 50-300 mg/l and ferric chloride 5-30 mg/l as Fe^{+3}. Rapid mixing was continued for 5 minutes, followed by 15 minutes of slow mixing at 30 rpm. Two hours after mixing, the supernatant was sampled. Total phosphorus analyses were then carried out on the supernatant samples and untreated control samples. Total phosphorus reduction to 1 mg/l or less was the prime criterion used to determine chemical and dosage.

The dosage used in the full scale tests was the one that reduced the total phosphorus to between 0.5 - 0.2 mg/l. Although this level is lower than the criterion of 1 mg/l residual total phosphorus, it was felt that the chemical might be less efficient in the field than in the jar test.

3.3 Application

3.3.1 Liquid Chemical (Alum or Ferric Chloride)

Prior to chemical application, a small portable floating dock approximately 6 feet by 12 feet (1.83 x 3.66 m) was anchored at the edge of the cell closest to the point of chemical delivery. In cases where the chemical delivery truck was unable to get close enough for direct discharge to the boats, the piping system for chemical delivery was then installed at this time. The boats (usually two) were launched into the lagoon and the inflow of raw sewage was diverted to another cell in the multiple cell installations.

The chemical was delivered to the site by tank truck; a 50-foot (15.2 m) length of 2-inch hose (5.1 cm) supplied by the carrier was normally adequate to run from the tanker to the boats (Figure 1). In other cases up to 1000 feet (305 m) of plastic 2-inch (5.1 cm) piping was used between the tanker and the boats.

The boats used in the experimental treatments were 16-foot (4.88 m) aluminum or fibreglas outboard motorboats

FIGURE 1: **Loading one of the boats with liquid chemical from an adjacent tanker.**

equipped with 40 to 55 HP (40.4 to 55.6 metric HP) motors. In two of the boats, a 150 gallon (681 litre) rectangular plastic tank was anchored amidships. In the third boat, two tanks of 100 and 150 gallon (454 litre and 681 litre) capacity were mounted in front of and behind the centre console (Figure 2). The latter boat proved more successful with its higher load capacity and easier access during application and clean up. Initially, a 2-inch (5.1 cm) valved siphon was attached to the stern of the tank near the bottom, and proceeded over the transom and down to a level just below the bottom of the boat. A 90° elbow directed the chemical into the prop-wash. In order to facilitate starting the siphon,

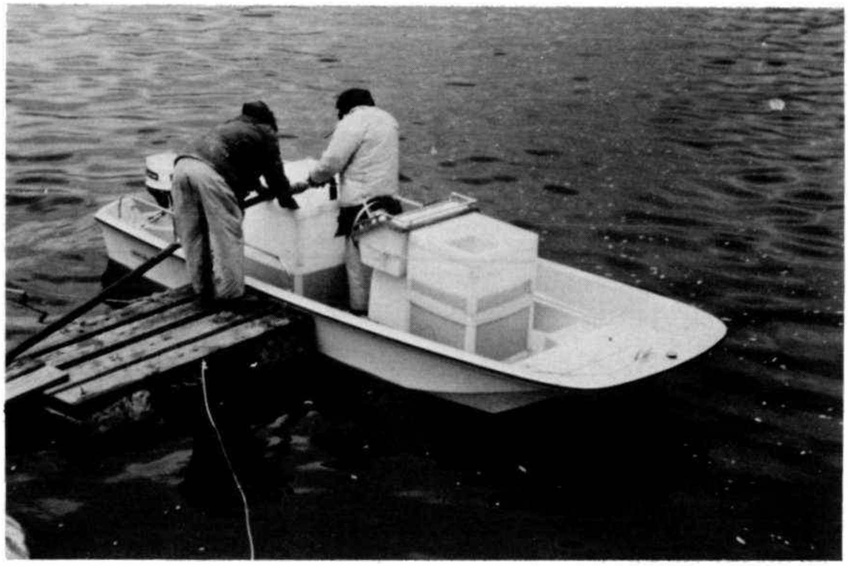

FIGURE 2: Loading the chemical storage tanks.

a hole, of approximately 1 inch (2.5 cm) diameter, was cut intc the leading edge of the last 90° elbow (Figure 3). A more permanent installation was later installed with direct discharge through the transom (Figure 4).

Personnel who were within splash distance of the coagulant wore rubber rain suits, plastic face shields and rubber gloves.

In distributing the chemical throughout the lagoon a random pattern of boat travel was used. Each boat operator attempted to cover the entire lagoon area in one or more 5 - 10 minute trips (Figure 5). Boat speeds were adjusted in such a manner so as to maximize the amount of turbulence produced (Figure 6).

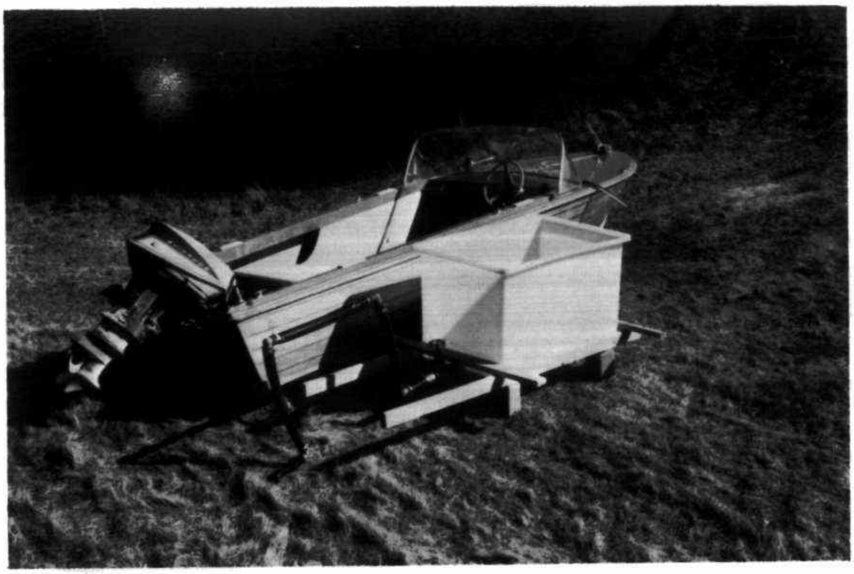

FIGURE 3: BATCH TREATMENT EQUIPMENT SHOWING WOODEN TANK SUPPORTS AND VALVED SIPHON SYSTEM.

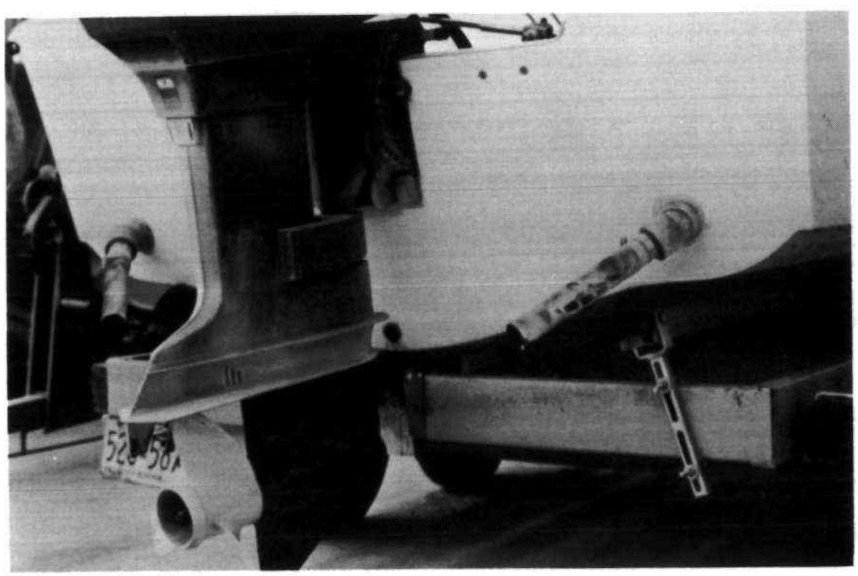

FIGURE 4: DETAILS OF PIPING THROUGH TRANSOM.

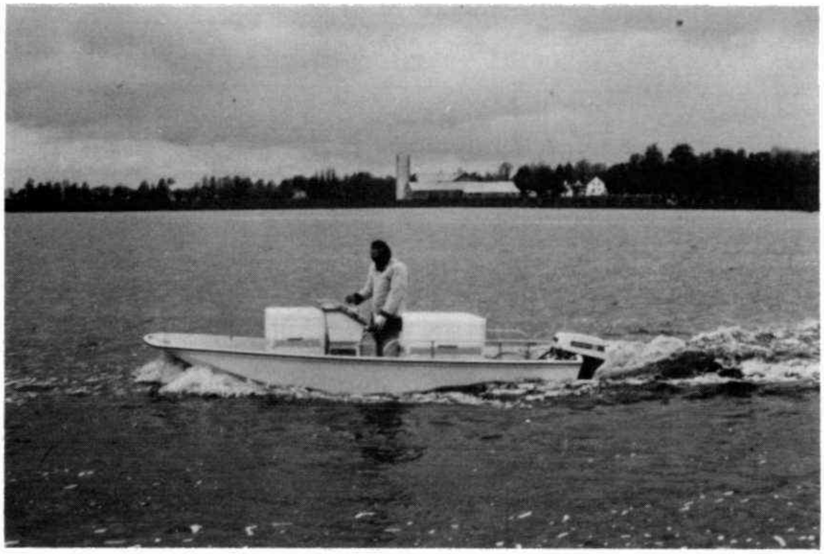

FIGURE 5: LOADED BOAT (150 GAL (681 LITRE)) DISPERSING CHEMICAL.

FIGURE 6: DELIVERY SIPHON OVER THE TRANSOM AND DEGREE OF TURBULENCE FOR ADEQUATE MIXING.

3.3.2 Dry Chemical

The site preparation for dry chemical treatment included dock installation, boat launching and sewage diversion, as outlined in the previous section. In the case of lime, which is only available in a dry form, a 600 gallon (2720 litre) slurry mixing tank was located adjacent to the lagoons (Figure 7) with a gasoline driven pump used to supply water to the slurry tank. A chemical transfer line, either pump or siphon, was installed from the slurry tank to the loading dock.

FIGURE 7: FIRST LIME APPLICATION, WITH SHORE-BASED SLURRY TANK, BAGGED LIME, AND ELECTRIC MIXER.

The dry chemical was delivered to the site in paper bags or small drums on transport trucks and unloaded either manually or by forklift onto a storage platform.

Dry lime was mixed in the slurry tank with lagoon contents and then delivered to the boat tank via the chemical transfer line. The same boats used in the liquid application

were used in the dry chemical work. In addition to the 150 gallon (680 litre) plastic tanks and the siphon dispersal equipment, each boat was equipped with a 110 volt generator connected to an electric mixer mounted on the 150 gallon (680 litre) tank. A man with a paddle was as effective as a mixer for keeping the slurry in suspension.

The Haliburton Jet-Slurrier method of dry lime addition was tested on one occasion. A bulk tanker loaded with dry lime under pressure was driven up onto the berm of the lagoon and connected to a Haliburton Jet-Slurrier mounted on the back of a pickup truck. Water from the lagoon was supplied to the slurrier by a 12 HP (12.1 metric HP) pump, thus projecting the mixture about 15 feet (4.5 m) into the lagoon. Outboard motorboats were operated in the lagoon during the application in order to maximize mixing and distribution of the chemical (Figure 8). Under ideal conditions, the tanker and the slurrier would have moved to various locations around the lagoon, although in this instance, berm condition and physical design did not permit this movement.

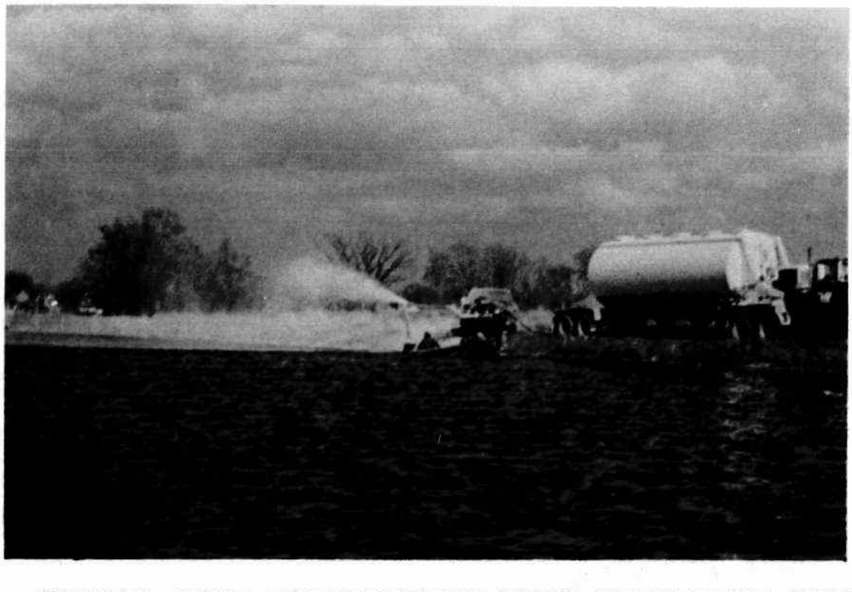

FIGURE 8: SECOND LIME APPLICATION WITH BULK LIME TANKER AND HALIBURTON JET-SLURRIER IN OPERATION. OUTBOARD MOTOR BOAT USED TO CREATE CURRENT AWAY FROM SHORE.

Alum and ferric chloride in a dry form have been used on a number of small lagoons. In contrast with lime these two chemicals go into solution readily. A pump supplied make-up water from the lagoon to the boat tanks where the dry chemical was mixed and then dispersed in the usual manner. The unstable and restrictive work area on the dock and in the boats made this method difficult and somewhat hazardous although it may be valuable where truck load quantities of liquid chemical cannot be used.

Protective clothing as outlined in the previous wet chemical system became more critical with additional dry chemical handling. The dry chemical also introduced a dust problem, necessitating the wearing of dust masks.

3.4 Discharge of the Treated Cells

The floc formed by the chemical precipitants (Figure 9) was given approximately 15 hours to settle out before discharging of pond contents began, usually the morning following treatment.

FIGURE 9: THE WHITISH FLOC THAT FORMS ALMOST IMMEDIATELY AFTER ALUM ADDITION.

Discharge was carried out as quickly as possible, given the physical limitation of the effluent structures, and the chemical and hydraulic loading limits of the receiving stream. It was usually completed in from 1 - 15 days, with the average discharge period being 8 days. The residual depth of water left in the lagoon after discharge was dependent on the design of the effluent structure, with these residual depths ranging from a few inches to two feet.

4. STUDY PROGRAMME

4.1 Feasibility of Batch Treatment

Preliminary work on batch treatment was carried out at the Arthur lagoons in the latter half of 1971. This lagoon system was chosen because it fulfilled the criteria outlined in the methods section, and had a sewage of mainly domestic origin thus avoiding any interference from unusual industrial wastes.

The dosage in this first treatment was determined by jar tests and "in-situ" studies. Full scale treatment was carried out in November, 1971, on the middle 5 acre (2.0 ha) cell, using liquid alum at a dosage of 325 mg/l, handled in the method previously outlined.

4.2 Use of Alum

In order to verify the results obtained in Arthur in 1971, one cell (15 acres) (6.1 ha) of the Tavistock lagoon system was treated in April, 1972 using 170 mg/l alum. A 17.7 acre (7.2 ha) cell at Aylmer was also treated in April, 1973 using 175 mg/l alum. Alum was discharged from the tanker truck directly to the boats as outlined earlier.

As noted below, alum was also used in full scale applications on a large cell treatment simulation, on an actual large cell, and also in testing the cumulative effects of batch treatment.

4.3 Use of Ferric Chloride

Ferric chloride as a precipitant in batch treatment was first tested on the small 2 acre (0.8 ha) cell at Geneva Park near Orillia, in May, 1972 at a dosage of 17 mg/l as Fe^{+3}. The method used was the modified version of the dry chemical method where the chemical was mixed in the boat tanks.

In order to confirm the results obtained in the Geneva Park treatment and also to assess the behaviour of the

precipitant over longer draw-down periods, three subsequent treatments using liquid ferric chloride were carried out. The first treatment was carried out on the 7 acre (2.8 ha) #3 cell of the Arthur lagoon system in October, 1972 (22 mg/l as Fe^{+3}) and the second on the 16 acre (6.5 ha) single cell installation at Sutton in November, 1972 (20 mg/l as Fe^{+3}). The third treatment was in the 7 acre (2.8 ha) #2 cell in Beaverton in April, 1973 (20 mg/l as Fe^{+3}).

4.4 Use of Lime

The feasibility of using hydrated lime as the precipitant in the batch treatment method was initially assessed on one 7 acre (2.8 ha) cell of the Tottenham lagoon system in May, 1972 using 250 mg/l as $Ca(OH)_2$.

The application was carried out over a three day period using the technique outlined for dry chemical application in the methods section above.

A second lime application in the Tottenham lagoon system on the second 7 acre (2.8 ha) cell (350 mg/l) in May, 1973 used the Haliburton Jet-Slurrier system previously discussed.

4.5 Large Cell Application

The simulation of a large cell application was carried out on the 5 acre (2.0 ha) Arthur #1 cell in May, 1972 by adding the required dosage (210 mg/l alum) in three equal amounts over a three-day period.

In May, 1973 the 27 acre (10.8 ha) #2 cell of the Listowel lagoon system was treated with alum over a two-day period. The standard liquid chemical handling system was used. In this application, the alum was pumped approximately 1000 feet from the tanker to the boats.

4.6 Single Cell Application

Many installations have just a single cell and raw sewage must continue to enter the lagoon during the chemical treatment and draw-down. This presents the possibility of

the effluent total phosphorus increasing above 1 mg/l before the pond is drawn down sufficiently.

To test the feasibility of batch treating this type of installation, the two lagoons (22.5 acre (9.0 ha) and 11.5 acres (4.6 ha)) at Chelmsford were treated using 170 mg/l alum. As raw sewage cannot be diverted from one cell to the other and the pipe connecting the lagoons was closed during treatment and draw-down, these lagoons could be considered as "single" although they differ in shape and retention time as outlined below. The smaller cell is twice as long as it is wide and the larger cell is essentially square. Raw sewage enters the two cells at about the same rate and the retention time for both cells combined was approximately 120 days over the summer of 1973. When not interconnected, the theoretical retention time for the smaller cell would be 80 days and for the larger cell 160 days at the raw sewage flow encountered in 1973. When both cells are drawn down simultaneously, they are lowered at the same rate, due to the design of the effluent structure. At Chelmsford the draw-down lasted for almost three weeks and the lagoon levels were reduced to 2 feet (0.6 m) from 5.5 feet (1.7 m).

4.7 Cumulative Effects of Batch Treatment

In order to assess the cumulative effects of batch treating one cell on a regular basis, the first cell treated in this programme, namely the 5 acre (2.0 ha) #2 cell at Arthur, has been treated a total of five times over a 24-month period. The first treatment was carried out in November, 1971 (325 mg/l), followed by treatments in May, 1972 (125 mg/l), October, 1972 (150 mg/l), May, 1973 (150 mg/l), and finally November, 1973 (150 mg/l).

4.8 Algae and Batch Treatment

To assess the effects of batch chemical treatment on algae, samples from many of the batch treated lagoons

were analyzed for the relative abundance of the genera present. An algae bloom of Microcystis aeruginosa was found in the 5 acre (2.0 ha) #2 cell at Wingham and treated with alum (100 mg/l). This species is one of the more objectionable types of blue-green algae that occasionally bloom in lagoons. It is a possible health hazard (Hughes et al., 1958) and has a characteristic foul odour.

5. DISCUSSION OF RESULTS

5.1 Primary Parameters

The effects of batch chemical treatment on the major water quality parameters are presented in Figures 10 to 13. These data indicate that the alum applications effected good chemical precipitation. Twelve to fifteen hours after treatment the majority of the alum-treated lagoons had total phosphorus contents of 0.1 to 0.2 mg/l, essentially the same as the soluble phosphorus concentration. The two lagoons treated with the lowest alum dosages, 100 and 125 mg/l, had residuals of 1.0 and 1.1 mg/l total phosphorus respectively. By thirteen days after treatment there was usually an increase in total phosphorus although this seldom exceeded 1.0 mg/l (Figure 10). The increase of total phosphorus after treatment was not evident in the soluble portion (Figure 11) which would suggest a resuspension of the precipitated phosphorus rather than a resolubilization. This resuspension is to be expected because of the mixing action of wind and waves on the shallow depths of water in the lagoon near the end of the draw-down period.

In most of the alum treated lagoons, the BOD values remained below 10 mg/l during the mean draw-down period (Figure 12). The probable mechanism of BOD removal is a mechanical entrapment of organic material in the floc formed by the coagulant. In two of the eleven lagoons treated there was an eventual return to about 20 mg/l BOD some 13 - 17 days after treatment. This could be due to a mechanical release due to mixing, since these two lagoons also showed an increase in the suspended solids. In the other alum treatments the immediate post-treatment suspended solids levels were generally maintained or improved over the mean draw-down period (Figure 13).

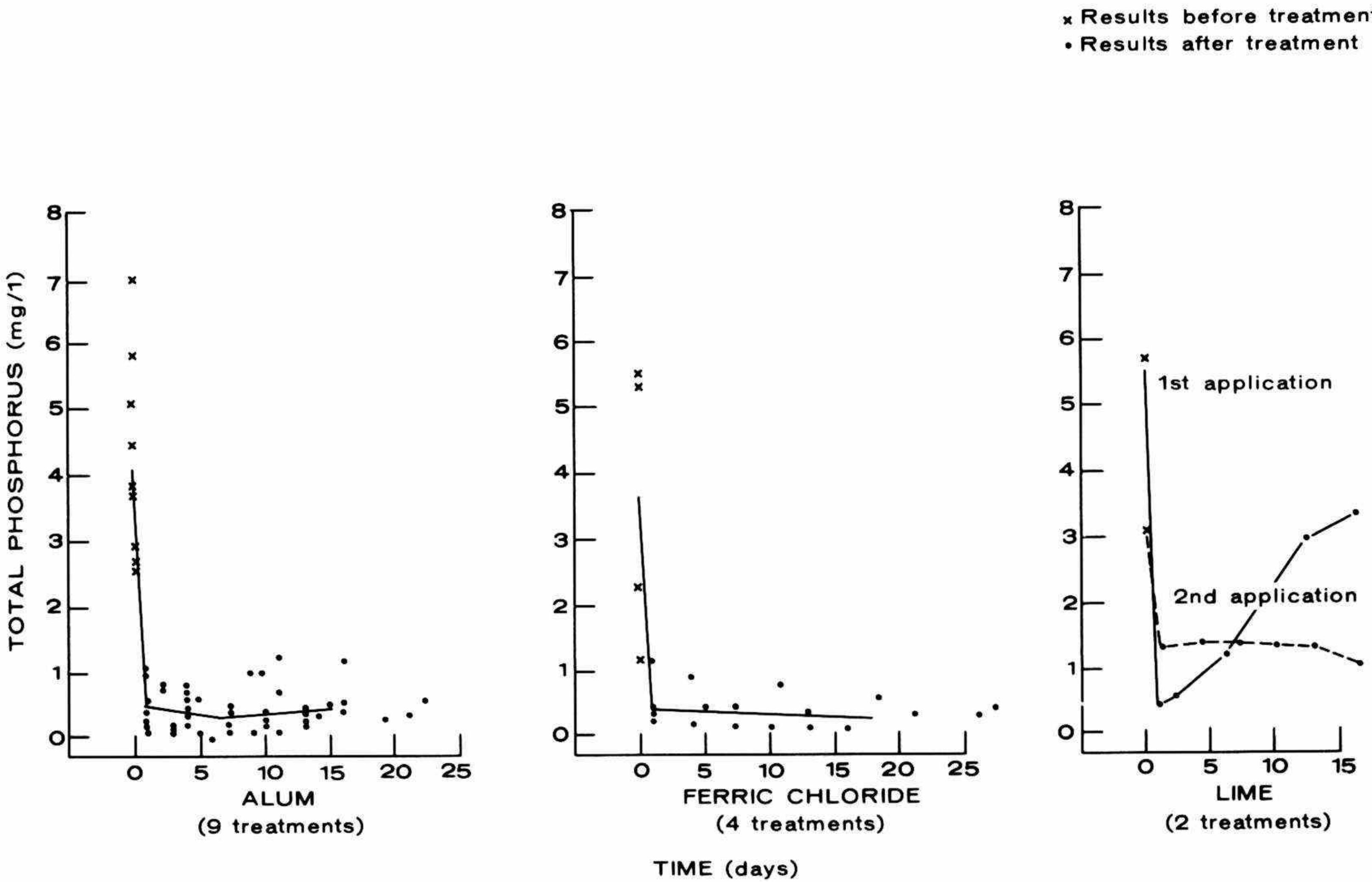

Figure 10 Response of total Phosphorus in seasonal Retention Lagoons after batch chemical treatment with three chemicals

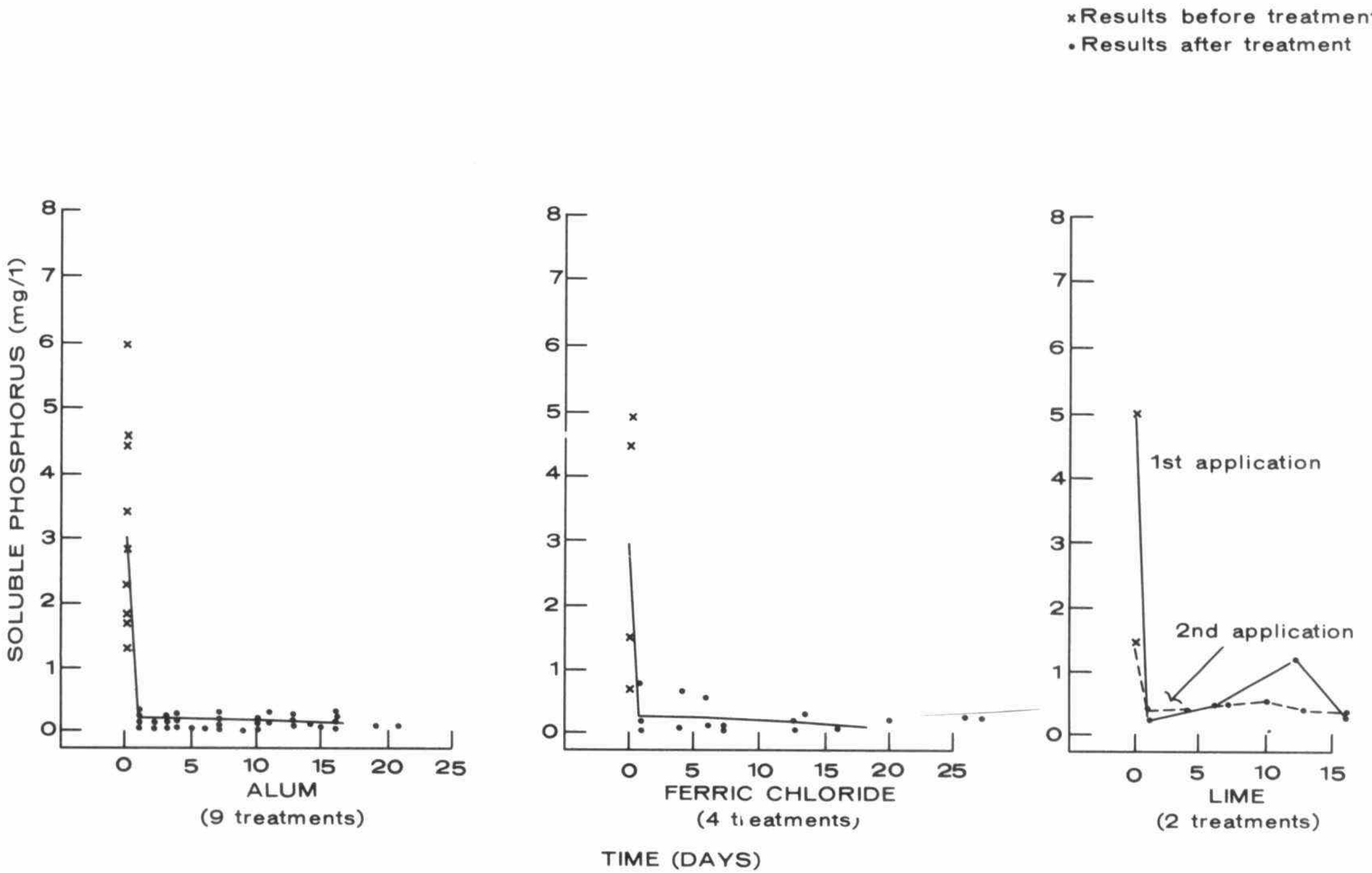

Figure 11 Response of soluble Phosphorus in seasonal Retention Lagoons following batch chemical treatment

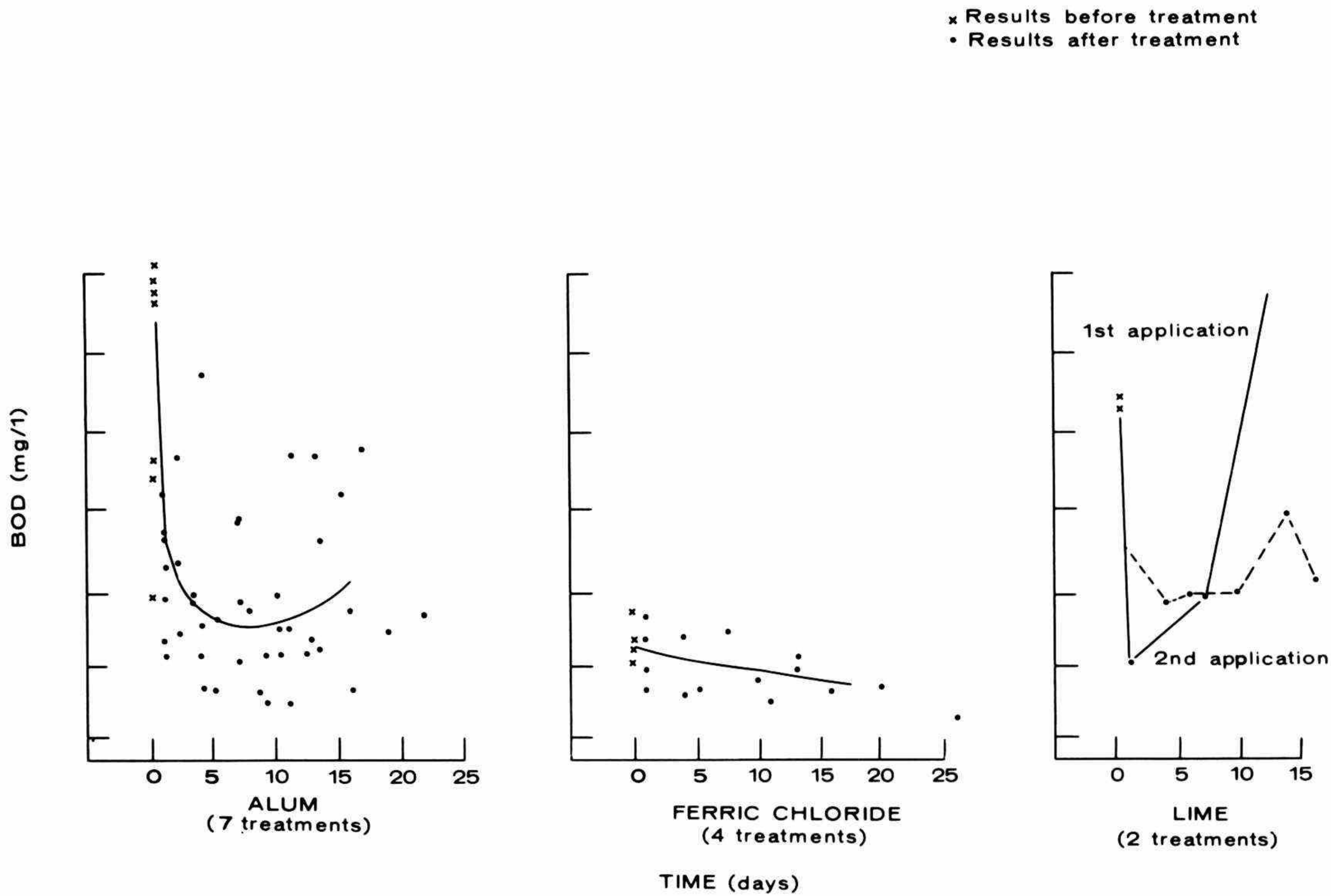

Figure 12 Response of BOD in seasonal Retention Lagoons
batch treated with three chemicals

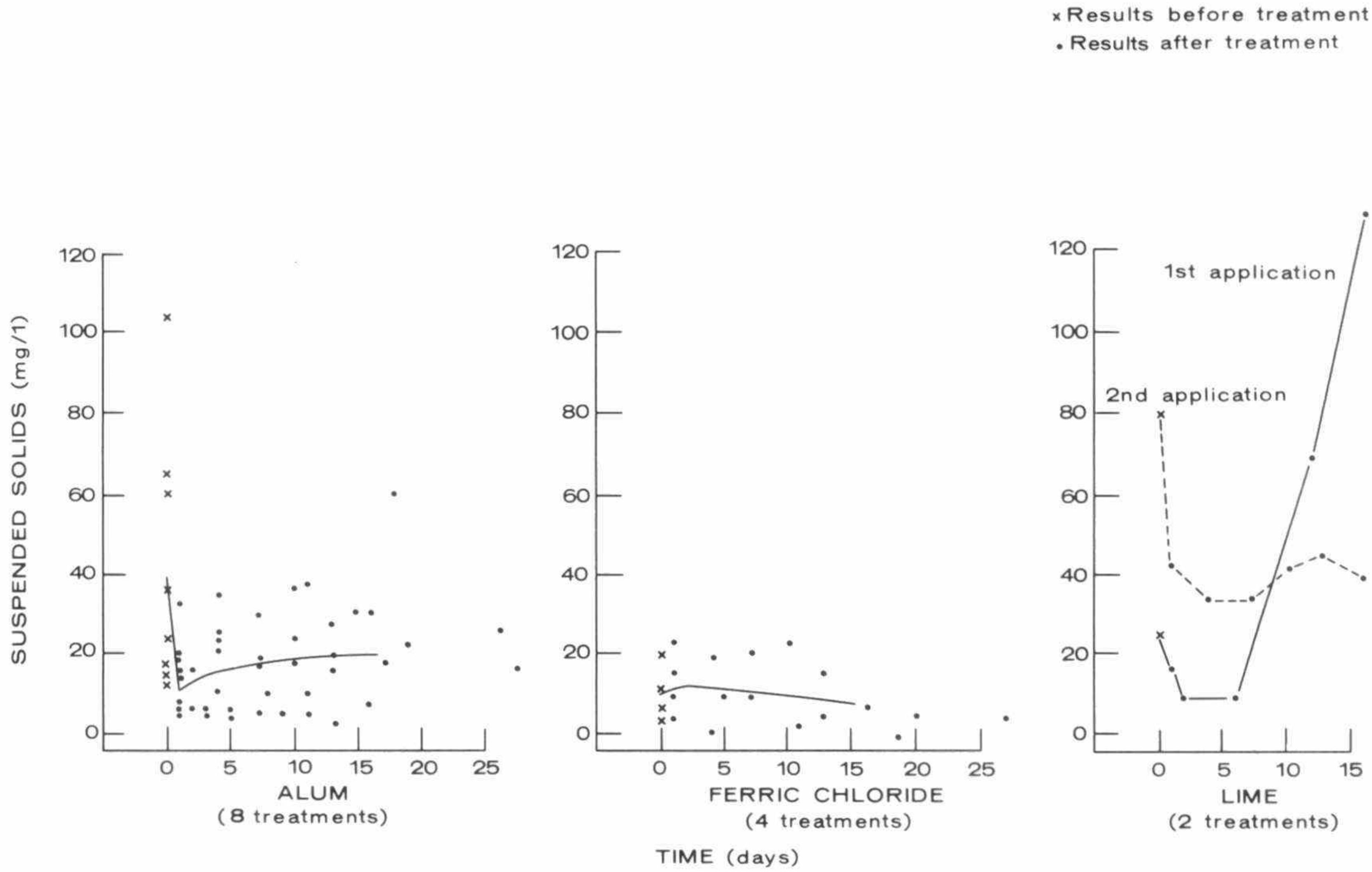

Figure 13 Response of suspended Solids in seasonal Retention Lagoons following batch chemical treatment

In the four applications using ferric chloride, the initial post treatment levels of total phosphorus were not as low as with the alum applications, with immediate post treatment residuals ranging from 0.4 mg/l to 1.2 mg/l total phosphorus (Figure 10). The 1.2 mg/l total phosphorus, encountered in Sutton immediately after treatment, was reduced to 0.95 mg/l three days later. In two of the four lagoons where the draw-down was similar to that in the alum treatments, there was no return of total phosphorus noted after the treatment.

BOD and suspended solids concentrations in all lagoons treated with ferric chloride were very low prior to treatment, and after treatment decreased only slightly (Figures 12 and 13). The effect of ferric chloride on high levels of BOD and suspended solids, as found in most of the alum-treated lagoons, is not known.

The first lime application (250 mg/l $Ca(OH)_2$) used a shore-based slurry tank and outboard motorboats to disturibute the slurry. The total phosphorus content dropped to below 0.5 mg/l after the treatment but had increased to almost 3 mg/l twelve days later (Figure 10). The soluble phosphorus was initially decreased, but increased to above 1 mg/l in twelve days (Figure 11). This increase corresponded to a drop in the pH to 8.7 from above 9.5. Twelve days after treatment, just under half of the total phosphorus was present in the soluble form, indicating that there was a resolubilization of the chemically bound phosphorus as well as a resuspension of the precipitate.

The BOD concentration in the first lime treatment showed an initial reduction to below 10 mg/l after treatment, then increased drastically to above pre-treatment values by twelve days after treatment (Figure 12). The concentration of suspended solids followed a similar pattern (Figure 13).

The second lime application using the Haliburton Jet-Slurrier at a dosage of 350 mg/l $Ca(OH)_2$ produced results which contrast sharply with those obtained in the first treatment. Although the residual total phosphorus was only 1.3 mg/l after treatment, this level was maintained for the following 16 days. Over this period the pH remained above 9.5. BOD and suspended solids levels after treatment were 13 mg/l and 44 mg/l respectively and these levels were also maintained over the 16-day period following treatment.

A number of factors may be responsible for the difference in results between these two treatments. The lower dosage, which possibly was unable to maintain the pH above 9.5, may account for the resolubilization of phosphorus in the first treatment. Possible differences in weather and thus differences in surface turbulance may account for the resuspension of the precipitate in the first application although this difference was not documented. The most obvious difference in the two applications was the heavy algae bloom which occurred in the first treatment after six days and did not occur in the second treatment. This would account for the drastic increases in BOD and suspended solids in the first application.

5.2 Secondary Parameters

The pH was reduced by approximately 1 unit in the alum and ferric chloride applications and did not fall below 6.5 during the draw-down of the lagoons. The pH increased by approximately 2 units in the lime applications and was not below 8.7 during discharge of the lagoons.

There was no noticeable effect of chemical precipitation on the nitrite, nitrate or ammonia concentrations in the lagoons. However, there was usually a reduction in the total nitrogen due to reductions in organic nitrogen, ranging from 0 to 7.5 mg/l, averaging 2.7 mg/l in seven treatments using all three precipitants.

Sulphate increases after treatment with alum were generally in the range of 100 mg/l with the residual sulphate levels ranging from 154 to 270 mg/l. In the one application where 325 mg/l alum was applied, the sulphate rose from 112 to 326 mg/l indicating a probable overdose.

As would be expected, an increase in aluminum concentration was noted following applications using alum. Only the highest dosage used (325 mg/l alum) rendered an immediate post-treatment aluminum residual above 1.0 mg/l. The 2.8 mg/l aluminum residual encountered in this treatment would again indicate an overdose of the coagulant. The immediate post-treatment residuals in the other five treatments monitored ranged from 0.3 mg/l to 0.9 mg/l aluminum. Also, a decline in the aluminum levels was noted over the draw-down period following treatment.

Iron as Fe^{+3} residuals after treatment with ferric chloride ranged from 0.45 to 1.3 mg/l. In two applications where long term monitoring was carried out, one application exhibited a 50 per cent decline in iron as Fe^{+3} 18 days after treatment while the other treatment maintained the immediate post-treatment level over this time period.

5.3 Bacteria

The range of bacteriological analytical results is presented in Table 1. In the alum applications, four of the six treatments produced total coliform removals of 97 per cent or greater and five of the six treatments exhibited fecal coliform removals of 98 per cent or greater. In these applications the lower residuals were generally associated with the higher dosages of alum and vice versa. During the draw-down period there was a slight increase in bacteria in one third of the treatments. Possibly the jar testing method could be developed to include prediction of disinfection as well as phosphorus removal.

TABLE 1. RESULTS OF COLIFORM BACTERIA IN SEASONAL RETENTION LAGOONS BATCH TREATED WITH THREE CHEMICALS.

	Total Coliforms (organisms per 100 ml)		Fecal Coliforms (organisms per 100 ml)	
	Before treatment	After treatment	Before treatment	After treatment
Alum (6 applications)*	1,600-120,000	6-2,400	100-22,000	4-530
Ferric Chloride (3 applications)	220-10,600	220-3,100	10-1,200	10-670
Lime (2 applications)	54,000-325,000	3,000-15,000	18-15,700	6-10

*Only six of the eleven alum applications are reported because of incomplete data due to late sample deliveries from field locations.

Bacterial removal in the ferric chloride applications ranged from 0 to 98 per cent. The case where no removal was noted had very low initial values (less than 220 total coliform per 100 ml and less than 10 fecal coliforms per 100 ml) and thus this low percentage removal does not properly reflect the performance of the chemical with respect to bacterial removal. This is borne out by the fact that in one application where substantial pre-treatment coliform levels were found, removals of total and fecal coliforms were 98 and 93 per cent respectively.

Ninety-nine per cent initial removal of both total and fecal coliforms was noted in the first lime application (250 mg/l lime). A rapid linear increase in bacteria after treatment was noted increasing the total coliform five-fold in the ten days following treatment. In the second application using the Haliburton Slurrier only 73 per cent of the total coliforms were removed. The fecal coliform population in this application was negligible and hence, no removal was noted. The higher dosage (350 mg/l lime) effected a lower removal efficiency, however, there was not the drastic return noted in the first treatment.

5.4 Large Cell Application

The simulation of a large cell application by chemical addition over a 3-day period on Arthur #1 cell in May, 1972, produced residual total phosphorus and BOD of 0.1 mg/l and 13 mg/l respectively. These results compare favourably with single day applications.

The 27 acre #2 cell of the Listowel lagoon was treated with 210 mg/l alum in May, 1973. The large quantity of chemical required (100 tons (90 metric tons) as liquid alum) necessitated an application over a two-day period. It was found that three boats were the optimum number to keep the alum flowing from the delivery vehicle almost continuously. The results of this treatment are presented in Table 2.

Again the results are very similar to batch treatments of smaller lagoons, so it appears the size of the lagoon has no effects on the initial efficiency of the treatment. The only complication that could arise is that the draw-down of a large cell could be excessively long (3 weeks or more) which might cause an increase of the BOD and suspended solids, and possibly an increase to above 1 mg/l in the total phosphorus if an algae bloom occurred.

TABLE 2. RESULTS OF BATCH TREATING A LARGE CELL (27 ACRES (10.9 ha)) AT LISTOWEL IN MAY, 1973 (ALL VALUES ARE IN mg/l).

	Total Phosphorus	Soluble Phosphorus	BOD	Suspended Solids
Pre-treatment	2.6	1.8	29	60
Treatment plus 1 day	0.2	0.02	5	19
Treatment plus 16 days	0.6	0.35	4	8

5.5 Single Cell Application

The results of the treatment and draw-down of the single cells at Chelmsford are outlined below. As pointed out previously, in batch chemical treatment with alum, there was a post-treatment drop in the fecal coliform bacteria with the possibility of only a slight return. Therefore, monitoring this parameter should reveal the raw sewage flow patterns and any short circuiting to the effluent of the raw sewage.

There was a general decrease in fecal coliform bacteria after treatment, reaching a minimum after six days. As can be expected due to incoming sewage the highest values

in each cell occurred in the influent area. In the narrower cell where the influent and effluent were on opposite corners of the lagoon, the values generally decreased further away from the influent, indicating that the raw sewage was mixing with the lagoon contents and not flowing to the effluent. However, in the cell that is essentially square, with the influent and effluent at the corners on the same side, there was evidence of some short circuiting with higher fecal coliform bacteria and supposedly raw sewage, along the side leading to the effluent.

The total phosphorus for the first week after the chemical treatment was essentially the same in both cells being generally less than 0.5 mg/l. But over the following week the average levels in the smaller cell increased to almost 2 mg/l, while in the larger cell they only increased to almost 0.8 mg/l. This indicates that for the best results in chemically treating a single cell lagoon, where raw sewage must continue to enter the cell, the intake and effluent structures should be as far from each other as possible, and if the draw-down time is two weeks the cell should have a retention time considerably greater than 80 days. Accurate predictions for other single cell lagoons while theoretically possible, would be difficult due to variations in raw sewage characteristics, mixing considerations within the lagoon, retention time, rate of draw-down, and initial post-treatment phosphorus levels.

5.6 Cumulative Effects of Batch Treatment

In Table 3, it can be seen that the dosage required to effect adequate phosphorus removal did not increase in each succeeding treatment on the same lagoon. On the basis of the pre-treatment jar tests, the alum demand stayed essentially the same and, with one exception, the total phosphorus results on the day following each treatment

TABLE 3. RESULTS OF SUCCESSIVE ALUM TREATMENTS CARRIED OUT ON THE #2 CELL AT ARTHUR.

Date	Dosage mg/l	Effluent Quality on the Day after Treatment	
		Total Phosphorus mg/l	BOD mg/l
November, 1971	325*	0.1	-
May, 1972	125	0.2	14
October, 1972	150	1.1**	16
May, 1973	150	0.5	15
November, 1973	150	0.2	6

*This dosage is a probable overdose. The dosage in the first treatment was decided in part by "in situ" studies, rather than only the jar tests used in subsequent treatments.

**On the next sampling, four days after treatment, the total phosphorus was 0.75 mg/l.

were quite uniform. This would indicate that either there is no recirculation of the previously precipitated nutrients or the effect of any recirculation does not persist until the following treatment.

Glass cores obtained in the fall of 1971 immediately after the first alum treatment on this cell showed a whitish layer up to 3/8" (1 cm) thick over the black sediment. Similar samples in November, 1973, immediately after the fifth alum treatment revealed a loose whitish layer about 1.5 inches (4 cm) thick; and at the surface, it appeared to be mainly lumps of floc 1 - 3 mm in diameter. Presumably, this whitish

layer is an accumulation of all five treatments and with time the last addition of floc would compact and dewater. Even if the compaction is not that pronounced the deposition rate would be only 0.3 - 0.38 inches (0.75 - 1.0 cm) per treatment. Only a little work has been done on this aspect of the project and these values should only be used as a rough indication of the rate of sedimentation in a lagoon after batch treatment.

5.7 Algae and Batch Treatment

It was found in the jar tests from the various lagoons that there was visually a proportional increase in the removal of algae with increasing dosages of chemical. This appeared to be due to entrapment in the floc.

The effect of alum treatment on the blue-green algae Microcystis aeruginosa was tested at Wingham (dosage 100 mg/l). In the jar tests there were visually slight reductions in the quantity of algae present. After full-scale treatment there was visually about the same amount of algae as before, although the chlorophyll "a" values, during the following two weeks, fluctuated greatly both above and below pre-treatment values. The alum treatment did not appear to decrease or enhance this bloom; however, there are so many variables which could mask any effect of the treatment such as temperature, or the physiological state of the algae, that no conclusive results can be reached. It should be noted that this was the minimum dosage for adequate phosphorus removal and possibly a higher dosage could have effected better algae removal.

Post-treatment algae blooms did occur in two lagoons about two weeks after treatment. One was treated with alum and the other with lime. In the former treatment, insufficient samples were taken, while in the latter treatment during the bloom period, there was a rise in the total phosphorus to above

1 mg/l and a rise in the BOD and suspended solids above pre-treatment values. Whether these increases were caused by the algae or by wind action on the shallowing lagoon is not known.

The batch treatment of lagoons is not likely to inhibit algal growth in the lagoons, since the post-treatment total phosphorus concentrations were well above 0.02 mg/l, the value generally considered adequate for a bloom.

5.8 Field Observations

5.8.1 Water Clarity

The Secchi disc reading in the alum treated lagoons ranged from 7 inches (0.18 m) to 16 inches (0.41 m) prior to treatments. The day following treatment, the Secchi disc readings in these lagoons ranged from 36 inches (0.92 m) to 60 inches (1.52 m), with four of the treatments having readings of 60 inches (1.52 m). In one treatment at Tavistock, the water clarity would have given a Secchi disc value far in excess of 60 inches (1.52 m) but that was the maximum depth of the lagoon (Figure 14).

Pre-treatment Secchi disc readings in the ferric chloride treatments ranged from 7 inches (0.18 m) to 20 inches (0.51 m). Following treatment, the range was 53 inches (1.35 m) to 60 inches (1.52 m). A slight orange tinge was visible in the water the day following treatment.

Lime treatments increased the Secchi disc reading from 8 inches (0.20 m) to 35 - 40 inches (0.89 - 1.0 m).

5.8.2 Foaming

Foaming at the point of discharge of the effluent was noted in applications with all three chemicals tested (Figure 15). Foaming was also noted during the discharge of some untreated cells, although it was not as pronounced.

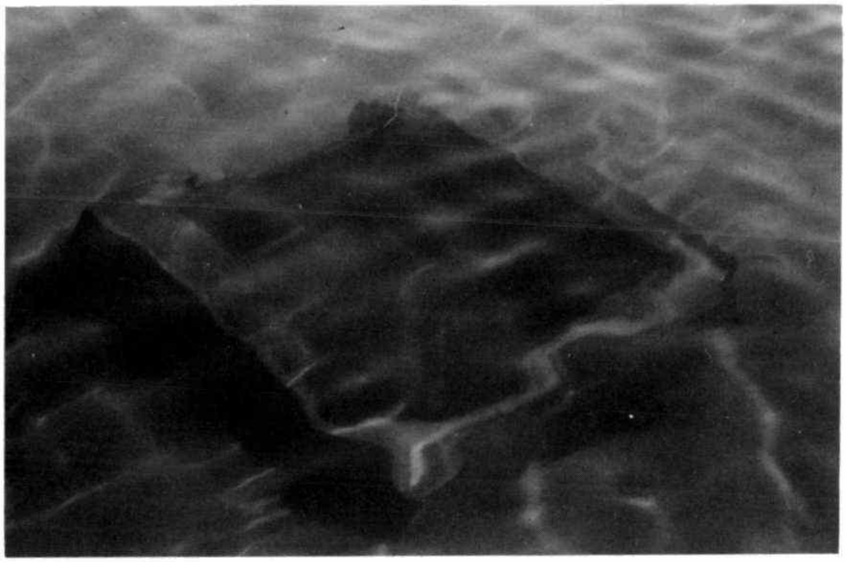

FIGURE 14: THE EFFLUENT STRUCTURE AT TAVISTOCK PHOTOGRAPHED THROUGH FIVE FEET OF WATER THE DAY AFTER ALUM TREATMENT.

FIGURE 15: EFFLUENT DISCHARGE AT ARTHUR SHOWING THE FOAM THAT DEVELOPED.

In discharging the treated lagoons, the turbulent mixing of the clear effluent in the discharge pipe caused foaming in the manholes along the pipe and also at the point of discharge. There was a build-up of foam in the receiving streams for approximately 100 feet (30.5 m) below the discharge point. Two hundred yards (182.9 m) below the point of discharge, this foam had virtually disappeared.

The foam from the Arthur #2 cell alum treatment in 1971, was collected in large plastic bags and returned to the laboratory for analysis. The residue from the foam was characterized as a mixture of synthetic anionic surfactants, the source of which probably was common detergents.

This foaming in the effluent may cause aesthetic problems in isolated instances where the discharge point is in a conspicuous area.

6. GENERAL CONSIDERATIONS

6.1 Application

The main application objectives in a lagoon batch treatment are rapid even distribution of the chemical and good mixing action. The outboard motorboat method described above achieves this objective.

The application times for full scale trials of batch treatment are presented in Table 4. As the man-hours spent in application vary with the quantity of chemical required, these application times are not directly comparable.

TABLE 4. LABOUR REQUIREMENTS FOR FULL SCALE BATCH TREATMENTS.

	Man-hours per acre	Man-hours per million gallons	Man-hours for set-up and clean up per application
Alum, liquid	2	1.6	16
Ferric Chloride,			
liquid	1.5	1.2	16
powder	13	9.6	16
Lime,			
dry chemical method	24	17.7	125
Haliburton method	1.7	1.4	16

6.2 Physical Design Requirements

If batch treatment is to be implemented on a regular basis, the following facilities are advisable:

1. A roadway to the edge of each cell with a turn-about area sufficient to carry 50 tons (45 metric tons) in early

spring and late fall or a piping system to deliver the chemical to each cell and a road adequate enough to get the boats to the lagoon edge.

2. A boat ramp and a small dock installed in each cell.

3. To maintain optimum effluent quality, in multiple cell installations, separate feed and outlet facilities are necessary to allow diversion of raw sewage during treatment and draw-down.

4. A low-level outlet pipe in the lagoon to allow complete drainage of the cell contents.

5. A discharge pipe from the lagoon of sufficient size and design to allow drainage of the treated area over a 5 - 10 day period.

6. In new large installations, a number of medium sized cells of 10 - 15 acres (4 - 6 ha) would be better suited to this type of treatment than one or two large cells. These medium sized cells could be treated individually and drawn down over a relatively short period of time, thus maintaining optimum water quality in the effluent.

6.3 Jar Tests

The prime criterion used in jar testing is the reduction of total phosphorus to below 1 mg/l. The procedure outlined above is an adequate method to determine the required dosages to effect phosphorus removal.

The jar tests gave a good indication of the post-treatment total phosphorus results in the lagoons, although there was some variation. In the alum treatments, this variation between the expected and the actual total phosphorus after treatment was as large as 0.6 mg/l but averaged 0.1 mg/l higher than expected. No definite relationship was found between the required dosage and the initial total phosphorus

in the lagoon, although there was a general trend towards higher phosphorus levels requiring higher dosages. It can also be said that there was more deviation from the expected values at the lower dosages. With the ferric chloride, the variation was about the same as with alum, but with the lime the actual total phosphorus after treatment was 0.2 to 1.1 mg/l higher than expected.

Jar tests should be carried out prior to each application since there is a considerable variation in chemical requirements at various locations. Also, subsequent treatments of the same cell may require different dosages, if raw sewage characteristics alter appreciably. Cells within one lagoon installation may vary due to size, age, operating procedure, etc.; thus, the dosage required in one cell may not be adequate for another.

The choice of a chemical should be based on individual chemical cost analysis as well as application economic analysis.

Jar testing should be carried out by a standard method to ensure reliable results.

7. CONCLUSIONS

The following conclusions can be drawn from the information obtained in this project:

1. Batch chemical treatment of seasonal retention lagoons can achieve total phosphorus residuals of less than 1.0 mg/l.

2. The effluent quality from a batch treated lagoon is comparable to or better than that achieved through conventional secondary treatment.

3. Batch treatment was effective in removing algae from the pond contents if the chemical dosage was sufficient. During the draw-down period, algae can have a deleterious effect on effluent quality if a significant bloom develops.

4. Liquid alum can be used effectively in this type of treatment. The limited work with ferric chloride was very successful but lagoons with a high initial BOD content were not treated with this chemical. Using lime, inconsistent results were obtained and, although the use of the Haliburton Jet-Slurrier showed some promise, further field trials are required.

5. In the case of liquid chemicals, the outboard motorboat method of application achieved good dispersal of the chemical and adequate mixing with the pond contents.

6. Batch chemical treatment is feasible on many existing lagoons that have an adequate retention time for winter storage. Some single and large cells can be batch treated but lagoons constructed specifically for this mode of treatment would ensure an ease of operation.

7. In five successive treatments of one lagoon, the dosage for adequate phosphorus removal did not increase and there was only a slight increase in the sediment depth with each treatment.

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